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Investigating the Long-Term Use of Exergames in the Home with Elderly Fallers

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ABSTRACT
Rehabilitation has been shown to significantly reduce the risk of falling in older adults. However, low adherence to rehabilitation exercises in the home means that seniors often do not get the therapy that they require. We propose that the use of tailored exergames could encourage adherence to falls rehabilitation in the home, as exergames have proved successful in clinical settings. We describe the results from the first known study to investigate the long-term (12 weeks) use of exergames, designed in close collaboration with elderly users, for falls rehabilitation in the home. Our findings suggest that there is an untapped potential of exergames for home rehabilitation use, as our findings show that there was better adherence to exercise in participants who used the exergames, versus those who used standard care. Finally, we make recommendations for designers, on the design of exergames for the rehabilitation of seniors.

Author Keywords
Games; Exergames; User Studies; Falls; Home; Elderly; Rehabilitation.

ACM Classification Keywords
H.5.2. [Information interfaces and presentation]; User Interfaces; Interaction Styles.

INTRODUCTION
In the United States, approximately a third of community dwelling older adults over the age of 65 years, and 50% of those aged 80 years and above, fall at least once a year [23]. According to two recent systematic reviews, the most successful intervention for reducing the rate (and risk) of falls is the use of specially tailored exercises designed to improve strength and balance in the elderly [20]. Based on current evidence, these exercises have been shown to reduce the risk of falling in older adults by over 30% [4, 8]. In many western countries, the most commonly used exercise programmes are based on the Otago Exercise Programme [4], and the Falls Management Exercise Programme [21]. The tailored exercises included in these programmes have been designed to target individual muscle groups to recover muscle strength and balance in older adults. The main therapeutic benefit of falls rehabilitation exercises stems from repetitive limb movements (mostly lower limbs), through particular ranges of motion. By doing this over time, lost function in muscles may be restored or improved [2].

As part of standard rehabilitation care in the United Kingdom, elderly fallers who cannot attend rehabilitation classes are typically given instructional booklets (and in some cases, videos) containing the aforementioned strength and balance exercises. Figure 1 shows a sample exercise from a booklet used in the home in the UK by fallers.

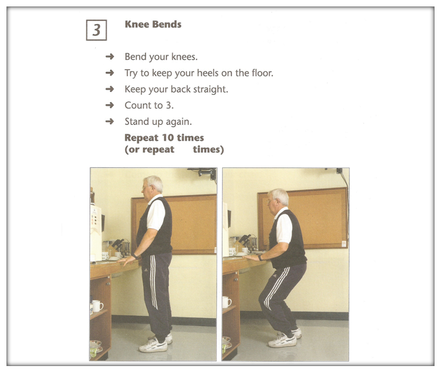

Figure 1: A sample exercise from the instructional booklet used as standard home rehabilitation care in the UK.

It is apparent from previous research that the strength and balance exercises used as part of standard falls rehabilitation care are therapeutically effective, and can reduce the risk of falling in the elderly [4]. However, evidence suggests that there is a problem with the uptake and adherence to rehabilitation programmes in the home [15]. This means that in numerous cases, fallers do not undertake the recommended amount of two hours of exercise per week [20]. This lack of adherence, and in some cases the discontinuation of the programme, may also result in a rapid decline of the benefits of any exercise that has already been completed, and an increased risk of falling.

There is an on-going debate surrounding the factors that are responsible for low adherence to exercise, even in other areas of rehabilitation that are not concerned with falls [6,

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10, 18], e.g. stroke. These main factors, according to the literature, have included: a) lack of motivation to continue [10]; b) low confidence in the programme [6]; and c) the nature of the exercise programme, or the way in which these exercises are presented to the user [18]. In particular, the repetitive movements involved in rehabilitation exercises (over a period of time) could potentially result in a reduced interest in the programme [25]. Therefore, there is a clear need to enhance home rehabilitation by seeking methods, which have the potential to increase motivation; and to distract the user from the monotonous but necessary repetitive movements required of these exercise programmes. One such method includes the use of computer games for rehabilitation, commonly known as exercise games or exergames.

Computer games and in particular serious games have received a high level of interest from researchers and health professionals alike [1, 9]. More recently, these games have been used, to great success, in research studies involving exercise in elderly users. Such purposes have included: recovering motor function in stroke patients [1], retraining balance [30], and encouraging physical activity [17]. There has also been an increasing interest in the use of commercial video games to aid the rehabilitation of older adults [22]. However, in rehabilitation, specific limb movements are required for effective therapy, which cannot be satisfied by commercial games. There are studies that have demonstrated the effectiveness of specially tailored exergames, for rehabilitation in stroke [1]. However, there is a lack of evidence regarding the effectiveness of the use of such tailored exergames to aid the rehabilitation of fallers. To address this problem we designed and developed, in conjunction with older users at risk of falling, exergames based on falls rehabilitation exercises [25].

In this paper we discuss the procedure and findings from a pilot randomized controlled home study to investigate whether exergames can encourage adherence to a home-based falls rehabilitation programme. This paper describes the first known attempt to investigate the long-term use of tailored exergames, designed with older users and based on a prescribed rehabilitation programme, in the home. We report on the effects of the use of these exergames, not just on adherence to exercise, but also on functional outcomes of walking and balance. Furthermore, we explore elderly users' experiences, the usability, and user attitudes towards the acceptance of our technologies for unsupervised rehabilitation in the home. Finally we make recommendations for researchers and designers on the design of exergames for elderly rehabilitation in the future.

RELATED WORK

Commercially available games have provided researchers with a low-cost solution to making exercise and physical activity a more enjoyable process for seniors. This is evident in the widespread use of Nintendo's Wii game console to encourage physical activity in older adults [22, 29]. One of the most common applications of the Wii in rehabilitation has been in the recovery of motor function in the limbs of stroke survivors [19]. One example involves a study conducted at the feasibility level by Yong Joo et al. [29], who explored the use of the Nintendo Wii to encourage the recovery of motor function in upper limbs. The findings from this study showed improvements in motor function in the participants. Moreover, the participants reported satisfactory levels of enjoyment and engagement compared to conventional stroke therapy.

McNulty et al. [11] also conducted a study where stroke patients were asked to play Nintendo Wii Sports over 14 days with additional therapy. Wii Sports is a collection of mini-games, including: tennis, bowling, boxing, golf and baseball (that are all controlled using gestures with the Wii remote controller) that mimic the actual limb motions required for each sport [14]. Although McNulty et al. found improvements in motor function in their participants; their balance did not improve in the same time period. Furthermore, the authors observed frustration in the participants, who complained about the speed and feedback provided by the Wii Sports games. This is expected because these games have been designed with healthy individuals in mind. Therefore, even though commercially available games can facilitate an enjoyable experience during exercise and physical activity, they also need to be effective from a therapeutic perspective. Alankus et al. [1] recognized this in their study where they investigated the use of specially tailored games to encourage full rehabilitation of affected upper limbs in stroke survivors. In this study two Wii remotes were strapped to the upper and lower arm of the participants. By moving their arms towards a screen, and pulling their arms towards their bodies, the participants were able to play games that mimicked the movements required of their rehabilitation exercises. Their findings revealed high levels of engagement in playing these games, which resulted in positive functional, and confidence, outcomes.

In this work we are interested in the use of exergames by elderly fallers in the home. Thus the inherent problem with the approach by Alankus et al., from a practical perspective, is the use of Wii remotes as orientation sensors strapped to the user's arm. These devices were designed to be remote controllers, instead of body-worn sensors. Therefore using them as body worn devices may result in an uncomfortable experience for older adults who carry out unassisted rehabilitation in the home.

Camera-based sensor systems, or optical sensors, possess the advantage of capturing movement from multiple sources. This has made such tools popular among researchers [7, 17]. Microsoft's Kinect camera sensor for the Xbox 360 platform has recently gained popularity among researchers as a cheap solution to facilitate full body interaction with games [7]. The Kinect system uses several infrared beams, and a depth camera to detect the distance of objects in the world [12]. This information is used to create a depth map, which when used in conjunction with a standard RGB (red, green and blue color) camera, can recreate a visualization of the environment that can be displayed on a screen. Ideally, camera-based technologies such as the Kinect sensor could provide users with a suitable tool for interactive home exercises, as it is inexpensive and relatively simple to use. However, one important factor to consider is that during rehabilitation patients sometimes need the support of an object, such as a chair, to help them undertake their exercises (e.g. Figure 1). In this case, the Kinect sensor (and camera-based systems in general) may not be ideal for such exercises because the chair would interfere with the user's image as detected by the system. Furthermore, a sufficient amount of space (which is not always available) is needed to allow camera systems to effectively detect objects in their field of view.

In the next section we will briefly describe the bespoke inertial sensor units that we developed, using relatively cheap off-the-shelf accelerometer, gyroscope and magnetometer sensors, to overcome the limitations of technologies used in previous studies. These sensors are small enough to be worn comfortably by the user, as well as free from the occlusion problems that may occur using camera-based systems. Furthermore, we report on the use of tailored (based on falls rehabilitation) exergames that were designed in close collaboration with elderly users, in the home for 12 weeks in a pilot randomized controlled study.

TECHNOLOGY

Wireless Inertial Sensors

We developed inertial motion sensors to facilitate interaction with the exergames, due to the advantages that it has over camera-based sensors, and it's suitability [28] for the purpose of detecting body movement. These sensors comprised of an accelerometer, a gyroscope, and a magnetometer, promoting 9 degrees of freedom [13]. The individual component sensors contribute to a device with the advantage of capturing precise body movements, while being small, non-intrusive, and occlusion-free.

Figure 2: The inertial sensor highlighting placement area.

Since these inertial sensors were designed to be body-worn, we ensured, in our previous user tests, that they were comfortable to wear [24]. The sensors (shown in Figure 2) included a Velcro strap, through which the users could comfortably attach them to their thighs (in a similar way to a belt). Other significant features of the sensors included: a red LED light to indicate power, a large accessible power switch, and a custom-built plastic case.

Hardware

The exergames were provided on a laptop computer (Toshiba Satellite L855; Intel Core i5 processor; 4GB RAM; AMD Radeon dedicated graphics card). We used a computer with a dedicated graphics card, rather than an integrated one, so that the 3-dimensional visuals of the exergames could be rendered without any loss of system performance.

Software

At the requirements gathering stage of the project we undertook design workshops with older adults at risk of falling (both fallers and non-fallers). One part of that workshop aimed to involve them in the design of games that provided the therapy promoted by their home exercise programme [25]. At the workshops, the participants used the exercises in the booklet to design game concepts based on these exercises. Once these exergames had been developed, we undertook user studies in the lab, and in the home, in order to test the games before full deployment in the home [24]. Furthermore, the users provided feedback on all elements of the software and hardware that were given to the participants in the home study. The software included four exergames, and five virtual physiotherapist exercises. We describe these software tools below.

Pigeon Express Game – Sit-to-Stand Exercise

The design of this game was based on the 'Sit-to-stand' exercise: one of the frequently used exercises to recover strength in the thigh muscles. The player controls a pigeon whose vertical flight corresponds to the users' sit-to-stand, and back to sit, movements. The objective of the game is to collect fruits (using the bird) that fall out of the back of a van – shown in Figure 3.

Figure 3: The Pigeon Express game allowed the player to perform the sit-to-stand exercise.

These fruits were arranged in a sinusoidal pattern in order to encourage the player to make the bird fly high, by standing, and make it fly low by sitting down. This game (and all of the games described in this paper) required two inertial sensors to play – one strapped to each thigh.

River Gems Game – Side Steps Exercise

In this game, the player steps to either side while holding on to a chair for support. The player character can jump from one log to another in order to collect colored gems that come towards the player. The objective of the game is to collect as many gems as possible, using the side stepping motion to control the direction of the jumps. Each green gem was worth one point in the score, while collecting five gems in a row allowed the player to collect a special purple gem that was worth three points.

Panda Peak Game – Marching Exercise

The Panda peak game was based on the Marching rehabilitation exercise. The player controls the walk of a panda character by marching on the spot while using the chair for support. The objective of the game is to make the panda walk across a log to the top of a hill in as quick a time as possible, without marching too fast. To discourage the player from marching too fast, the character would wobble for a few seconds (when quick marches are detected by the sensors) before falling off the log.

Horse Hurdles Game – Knee Bends Exercise

The 'Knee bends' exercise requires the user to bend to a 'half squat' position, hold this position for three seconds, and then return to the standing position. In the game, the player controls a racehorse that jumps over hurdles while galloping. By bending at the knee, the horse gallops faster, while standing up makes the horse jump. The objective of the game is to jump over as many hurdles as possible.

Virtual Physiotherapist Exercises

There were nine exercises in total included with the home rehabilitation programme. The four exergames described above represent four of those exercises. The remaining five exercises required more subtle movements of the legs. During development and testing, of the sensors, we found a possible error margin of up to 5 degrees of orientation. Since the ranges of motion required by the five exercises, were close to, or smaller than, this error margin, we used a different type of feedback for these exercises (Figure 4).

Figure 4: The virtual physiotherapist demonstrating the 'Stepping foot behind' exercise.

This was mainly because the error could potentially result in undesirable feedback; therefore, the remaining five exercises were delivered through passive feedback involving a virtual physiotherapist. The virtual physiotherapist character was animated to show how the exercise should be done, while the users were expected to follow these movements.

METHOD

The main study was a two-arm pilot randomized controlled trial in the home over a period of 12 weeks. This is the amount of time that the fallers are expected to attend exercise classes, following recovery from a fall. The objectives of the study were as follows:

1. To investigate the effects of using exergames on adherence to a home-based falls rehabilitation programme (this was the primary objective).
2. To determine the effects of using the exergames on functional walking and balance.
3. To investigate the user experience, and acceptance of the exergames by elderly fallers in the home.

The first group of participants (booklet group) received the standard care booklet as part of the control for the study. The second group (exergame group) received both the booklet and the technologies (sensors and computer, with exergames) as the intervention. All of the participants received training, from a research physiotherapist, on doing the exercises effectively in the home, using the booklet. The participants in the exergame group were also trained on the use of the technologies; this consisted of: strapping and switching on the sensors, and performing all of the exercises using the software-based instructions. All of the participants were asked to contact the researchers, by telephone, if they encountered any problems with the study or the technologies.

Recruitment and Participants

Seventeen participants were recruited from the local falls service following ethical approval granted by one of the UK National Health Service research ethics committees. Participants were included in the study if they: a) were over the age of 65 years; b) had had at least one fall 12 months prior to taking part in the study; c) were living in the community; and d) were able to give informed consent.

Study group	Distribution of participants
Booklet group (control)	9 participants (1 male, 7 females); mean age: 75
Exergame group	8 participants (2 male, 6 females); mean age: 76

Table 1: Distribution of the participants for the home trial.

Included participants were then randomized, using a computer-based random allocation system, by an independent establishment. Table 1 shows the distribution of the participants that were recruited. There were significantly more females in the study than there were males. This was indicative of the fact that it was predominantly women who attended the exercise classes where the participants were first approached. All of the participants were educated to at least high school level with some of them having worked in professional fields.

Outcome Measures

Adherence to Exercise

The primary objective of the exergames was to encourage adherence to a home-based falls rehabilitation programme. Exercise diaries were provided so that the participants in both groups could record their exercise sessions; one session comprised of all 9 exercises in the programme. In the exergame group, the computer also automatically logged the exercises that the participants completed over the 12 weeks, whereas in the standard care group we relied on self-report only.

Functional Walking Speed and Balance

We measured the participants' functional abilities, at the start and again at the end of the trial, in order to determine the effect of the use of the booklet and exergames on their risk of falling. Since faster walking speeds are associated with lower risk of falling in the home [16], walking speed was captured in the laboratory using a GAITRite walkway system. This is a mat with thousands of pressure sensors that can determine the position and speed of the users' steps as they walk across a mat [26]. Impaired balance is also a critical risk factor associated with falling [22]. Balance was measured using the clinical Timed up and go (TUG) test. The test involves getting up from a chair, walking 3 meters, then turning and walking back to the chair before sitting back down. Completing this test in a time greater than 14 seconds indicates a high risk of falling [27].

Confidence and Fear of Falling

Fear of falling, and low confidence, are known risk factors for falls [23]. We explored these through questionnaires and interviews, during the home study, to determine whether exergames could reduce fall risk through these outcomes. The participants were asked how confident, and fearful, they felt in maintaining balance during set daily activities, including while performing exercise.

User Experience and Expectations

Most of the elderly fallers included in our home study had previously used booklets (and in a few cases videos) to exercise in the home. However, several of them had not used a computer in the past. Therefore, through qualitative methods, using questionnaires and interviews, we explored: a) the expectations that they had regarding the use of the hardware and software technologies (at the start of the trial), and b) what their experiences were with the use of these tools in the home. We investigated, again at the end of the trial, whether they felt that their expectations had been met through playing the exergames.

Acceptance of the Technologies

In our previous user studies, all of the users reported that they would be willing to use the exergames in the home over an extended period of time [24]. In order to test this with the users in our trial, we investigated the acceptance of the technology in our home study. The participants provided feedback on acceptance throughout the trial by filling out questionnaires and taking part in an interview at the end of the trial.

Interaction Methods

The users accessed the individual exergames using the numerical keys on the laptop keyboard. The keys that were needed to access the exercises (keys 1 to 9) were covered in high visibility labels to help the users identify the necessary keys. At the end of each exercise, a tick appeared on the exercise on-screen button so that the users could tell which exercises they had completed.

There were help instructions provided on the screen describing how the system worked, including: strapping and switching on the sensors, and reminders showing how the exercises should be done. These instructions were informed by the users' feedback in the user studies carried out in our previous work [23]. The main steps involved in one exercise session with the computer games involved:

1. Switching on the computer.
2. Strapping and switching on two inertial sensors.
3. Selecting, and doing either the automatic programme (all of the exercises), or selecting individual exercises from a list.
4. Taking off and charging the sensors; and shutting down the computer.

The participants were asked to fill in the diary at the end of each exercise session.

FINDINGS

Five participants (4 females and 1 male) dropped out from the study prior to completion – four from the booklet group and one from the exergame group. The reasons were varied but were not as a consequence of doing the exercises. Two of the participants who dropped out fell outside their homes and were admitted to hospital. One of them fell ill for an extended period of time, while the remaining two had pain in their knees and were advised by their doctors that they should abstain from exercise for a while. Here we report on the findings from the study based on the twelve participants who completed the study.

Adherence to Exercise

In the home study, the exergame group participants completed an average of 38 sessions (SD = 9.9), compared to 19 sessions (SD = 25) in the booklet group. The large spread in the booklet group was due to outlier data from one participant, who reported 5 sessions, on average, per week; this was significantly more than the other participants reported in this group. The trend lines, shown in Figure 5, were generated through an analysis of the data (on adherence) using Microsoft® Excel for Mac 2011. It is evident, from these trend lines, that the exergame group maintained the exercise programme better than the booklet group, with the line never falling below the recommended minimum amount of exercise.

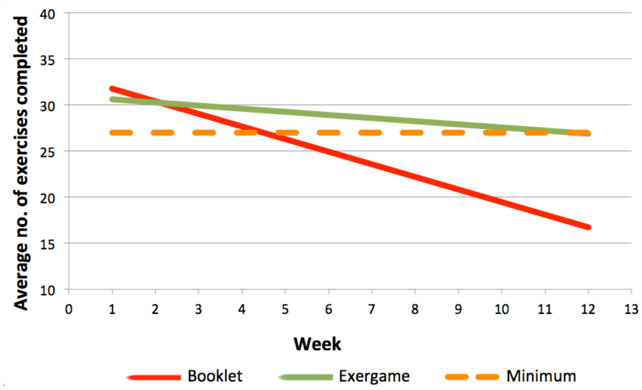

Figure 5: Diagram showing longer-term adherence to the exercise programme in each study group.

The difference, in adherence trends, was analyzed for statistical significance using IBM® SPSS Statistics (Version 19). The result was not found to be statistically significant at a significance value of $p = 0.05$ ($p = 0.097$). However, with this significance value of 0.097, there is an evident trend towards significance. A comparison, of the adherence data, from both the computer (in the exergame group) and the diaries showed that the self-report figures, although very close, did not always exactly match those logged by the computer. This indicates possible inaccuracies in the diary reporting.

Adherence was also explored qualitatively, at the end of the study, through an interview and questionnaire. We found that one participant in the exergame group developed pain in her knees, and she was advised by a physiotherapist to stop exercising for a few months. This could have negatively affected the trend seen in the exergame group. Two of the participants in the booklet group hardly completed any exercises (one session, or less, per week) after the sixth week of the study. These participants reported that they often felt 'bored and too lazy to exercise'; as a result, they did not feel motivated to continue with the exercise programme. In the exergame group, the primary reason for doing the exercises was a sense of engagement while playing the exergames. The scores, in addition to the interactive nature of the exergames, the participants disclosed, provided this element of engagement. The participants tried to beat the previous scores that they had achieved, leading to consistent participation in the exercise programme, over the 12 weeks. The ability to view progress (through better scores) was also found to afford an additional boost to confidence in physical ability.

Functional Outcomes of Walking and Balance

Walking Speed

On average there was a 5% improvement in walking speed in the exergame group, while a 4% reduction in walking speed was found in the booklet group (Figure 6).

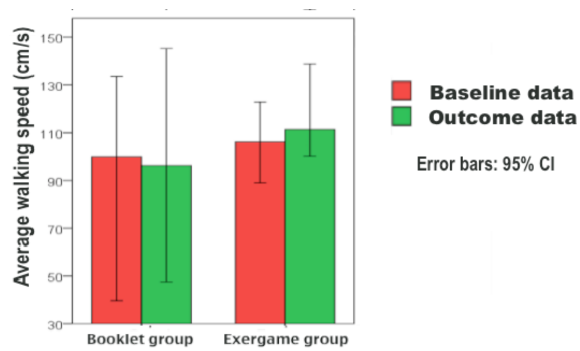

Figure 6: Differences in walking speed between the two study groups from baseline to outcome (Higher=Better).

The differences in these changes, between the study groups, were not found to be statistically significant (Mann Whitney $U = 9$, $p = 0.101$). However, with a significance value of 0.101, it is evident that there is also a trend towards a statistically significant difference (at $p = 0.05$) between the exergame and control groups. Exploring the data on an individual level, five out of the seven participants in the exergame group approached, or exceeded, the significant change amount of 0.1m/s in walking speed [5] over the study. In comparison, only one participant in the control group saw the same level of improvement.

Balance

Balance was explored using the Timed up and go (TUG) test. Figure 7 shows the differences in this outcome measure across the groups in the study.

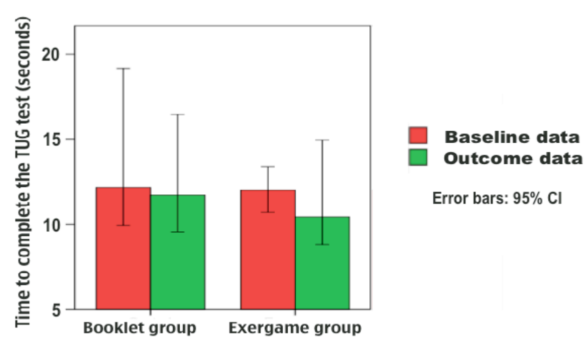

Figure 7: Results from the TUG test across the study groups (Lower = Better).

Statistical tests showed that the differences in TUG improvements were not statistically significant (at $p = 0.05$)

between the booklet and the exergame groups (U = 13; p = 0.265). On an individual level, six participants improved, with four participants achieving times of less than 10 seconds – indicating low falls risk [27]. Out of these participants, one of them belonged to the booklet group, while the remaining three were in the exergame group.

Confidence and Fear of Falling

At the end of the trial five of the participants in the exergame group reported that they felt more confident in their balance, and less fearful of falling, as a result of playing the exergames over time. They credited the reduction in fear to the fact that because they felt engaged in playing the exergames; they hardly concentrated on the fear. The remaining two participants in the exergame group said that they did not feel any more or less confident or fearful of falling. However, these participants didn't think that they had issues with confidence or fear at the start of the trial. In contrast, two of the participants in the booklet group felt more fearful of falling, with the same level of confidence that they had at the start of the trial. Only one participant (who did 5 exercise sessions on average per week) in this group felt that their confidence had improved.

User Expectations of the Technology

At the start of the trial, the participants in the exergame group were asked what their expectations were of the technology, and what they felt the implications were for effective rehabilitation in the home using the exergames. The majority of the participants were looking forward to playing the exergames over the 12-week trial duration. They attributed this to the fact that they enjoyed playing the exergames during the training session, and they felt that these games would encourage, and motivate, them to do more exercise in the home. Although the quantitative outcomes of the study did not achieve statistical significance, a majority of the exergame group participants felt that their expectations had been met, as regards motivation to exercise. Furthermore, most of them felt that their balance and mobility had improved.

User Experience, Usability, and Acceptance

Booklet

The participants in both groups were given a booklet to use for their home exercise programme; this was because this is considered to be standard rehabilitation care in the UK, and it was required for ethical approval. The participants in the booklet group considered the booklet easy to use and convenient. However, only one participant reported that he enjoyed using the booklet. The main reason for this, he remarked, was that he liked the clarity of the pictures, and that the instructions were clear to him. Two of the participants reported that they considered the experience of using the booklet a boring one, and did not exercise as much for that reason. When asked what the primary reason was for adhering to the exercise programme in the home, the most common reason was that they were taking part in a research study and had to record the sessions in a diary.

Exergames

Only two of the participants in the exergame group used the booklet to exercise. However, they reported that they only did this when they went away from home for a few days. All of the participants considered the experience of using the exergames a positive one. This is evident in some comments from the open-ended questions on their experiences with the exergames (Table 3).

User A	*"The games were quite interactive, and it prevented me from having to look down in a book; I was always trying to get high scores".*
User B	*"If I did not have the games I don't think I would have been as motivated to exercise; I realized the importance of keeping active".*
User C	*"I looked forward to exercising with the games because it was much easier than following a book. I thought they were fun and they made me want to do more of the exercises".*

Table 3: User comments on using the exergames to exercise in the home over 12 weeks.

Four of the participants recorded twice as many exercises completed with the exergames than they did with the other exercises (using the virtual physiotherapist). They attributed this to the fact that they enjoyed playing the exergames much more than they enjoyed doing the other exercises with the virtual physiotherapist. However, all of the participants in the exergame group remarked that they found the virtual physiotherapist exercises very useful due to the similarities to an exercise class. Furthermore, the ability to see this animation, of exercise movement, assured the participants that they were doing the exercises the correct way. Although there wasn't any one game that the participants did not enjoy, the River Gems and Horse Hurdles games were enjoyed the most. This was credited to the humorous nature of the Horse Hurdles game, and the natural environments used in the River Gems game, which were found to be aesthetically pleasing. Through a questionnaire the participants were also asked to rate, using a Likert scale of 5 items, how well they thought each game promoted the right quality of movement required for its corresponding exercise. The highest scoring exergame in this category was the River Gems game (with an average rating of 5, compared to 4 in the other games).

When asked to comment on the scoring system in the various exergames, the participants all agreed that the scores were very useful; and in some cases the primary motivator for long-term use of the exergames. The special purple gems included in the River Gems game were considered a useful incentive, by most of the participants, to encourage the player to perform better at the game. The rest of the participants were indifferent to this implementation, revealing that they considered these items just regular collectible items.

Each game came with different upbeat musical tunes to encourage an active virtual environment. Only one of the participants liked the upbeat nature of the music. The majority of the participants were neutral on the music, whereas two of the participants did not like the selection. The participants expressed a desire to customize the music to their particular tastes, as music promoted a more enjoyable experience for them in group-therapy classes that they had previously attended.

Usability and Acceptance

The System Usability Scale (SUS) was used to investigate user satisfaction with the usability of the technologies. The average rating of the system by the participants was 89.6 out of 100, indicating high user satisfaction [3]. Two of the participants in the exergame group rated the system as 'acceptable' (scores of 75 and 78), while the rest of the scores were above 90 (excellent). Through the qualitative results we found that, on two occasions, the computer wouldn't shut down when one of the participants pressed the power button; this was due to Microsoft Windows processes running in the background. The problem was resolved by shutting the computer down. The participants remarked that they found the sensors easy to use and manage. One of the participants reported that on two occasions during the twelve weeks, she felt that one of the sensors was problematic. This was obvious to her during the River Gems game, because the character did not move when she stepped to the side. She found out that this was due to a low charge on the battery.

Aside from the problems highlighted above, all of the participants considered the technologies easy to use and free from usability problems. The participants were asked whether they were likely to continue using the exergames past the 12 weeks if they could. Only one participant said that he would not; mainly because he did not believe that he required any more exercise than he got from his daily activities. The rest of the participants said that they enjoyed the exergames and were likely to continue using them. There were also comments that because the computer was easy to use, there was an improvement in confidence regarding using technology for rehabilitation. These comments came from the participants that had no previous experience with using a computer.

DISCUSSION

Adherence and Effective Therapy

Compared to the booklet group, the findings revealed improved adherence rates to the exercise programme in the exergame group. The level of engagement, afforded through the use of the exergames, motivated the participants, who maintained the exercise programme over the 12 weeks. The main elements that contributed to increased engagement, in the exergame group, were: interactivity, competition afforded through game scores, and increased confidence through noticeable progress over the long term. In contrast, there was a steady decline in exercise adherence in the booklet group, for most of the participants; with them suggesting that exercise was boring with the booklet. This was found (in the booklet group) to be the main factor influencing low adherence in the latter half of the home study. One factor to take into account is that adherence, in both study groups, was measured through the use of diaries, which may include incorrect information because it is based on self-report.

Balance was found, through the quantitative results, to improve in some of the participants in both groups; however the differences in these outcomes were not found to be statistically significant. We expect that the duration for the study was too short to show any significant change (or differences in change) in balance in the study groups. Although the results, from walking speed, did not achieve statistical significance, they suggest that mobility improved in the exergame group. We expect this to be due to the fact that the core exergame mechanics were modeled on the exercises included in the booklet. The advantage that these exergames have, over the booklet, is that they encourage, not just the range of movement required, but also the correct pace of movement [24]. This could make a significant difference, from a therapeutic perspective, because these exergames promote the recommended quality of movement for effective rehabilitation. On the other hand, there are situations where older users preferred to use the booklet, e.g. convenience, and going away from home for a few days. While the booklet might be more convenient, in such cases, there are implications for effective therapy that may arise as a result of using the booklet during exercise [24]. One of the main problems with the booklet is that rehabilitation progress cannot be observed through this medium. In the case of our exergames, improved scores were an indication of rehabilitation progress, since these exergames were tailored to proven effective rehabilitation exercises. This progress was found to improve confidence and reduce fear of falling in older adults, as found through the qualitative results of our home study. All of these factors contribute to a possible reduction in fall risk in the participants who used the exergames.

The study findings also show high levels of usability and satisfaction through the SUS and participants feedback. With the exception of a few technical problems, the participants were able use the system and sensors without difficulty. Acceptance was found to be high regarding the use of the technologies, due to the advantage offered by these technologies in the home.

Study Limitations

There are limitations with the work presented in this paper. First, there were factors that prevented us from achieving statistically significant results in the home study. These include: a) the small sample of participants; b) all of the participants received the exercise programme, which meant that the differences would be minimal in participants who engaged in exercise, regardless of the intervention; and c) significant improvements in mobility and balance are often found in extended trials conducted over a year [4]; in our case, the study was a 12-week pilot study. Furthermore diaries, which are based on a subjective self-report method, were used to measure adherence in our study. Additional work is needed to confirm the findings on adherence, and functional outcomes, reported on in this paper.

Recommendations for the design of exergames

We derive our recommendations from both user feedback, based on their preferences and design requirements, and the lessons that we learned from the home study findings.

Model Exergames on Evidence-based Therapy

We would encourage designers to ensure that exergames are modeled on evidence-based rehabilitation programmes, as these exercises promote the ideal quality of movement required for effective therapy. One possible way to ensure that the potential of these exergames is realized is to make sure that a scoring system is included, and that the scores are relevant to metrics of improved therapy (e.g. range and pace of movement) and not some other arbitrary measure.

Communicate Progress

We recommend that progress be communicated to older users through exergame scores. In our study, this was found to give the participants a motivational boost, which encouraged them to maintain the exercise programme. If exergames are tailored to rehabilitation exercise and progress is modeled on exergame scores, improvements in these scores will correspond to improved physical function.

Enable Choice Where Necessary

Certain aspects of exergames need to be static, such as the core mechanic, because it should emulate the exercise that it is modeled on. However, there are aspects of the exergames that our users felt could benefit from customized options, such as: music, collectible objects, and background elements. The rationale for this was two-fold. First, the participants argued that people had different tastes in music. They felt that they would have preferred to select, from a list of musical tracks, which ones they wanted in the games. Secondly, they suggested that changing the elements of the game, while maintaining the core mechanic, could keep the game fresh, and prevent the users from losing interest in the game over extended periods of use.

Use Animation Instead of Images and Text

Based on feedback from older users in our previous work, we removed text-heavy instructions and replaced them with image-based ones [24]. This was because the users felt that they could get bored reading the text, as they often do with the booklet. In this study, we explored the participants' opinions on the animated virtual physiotherapist that demonstrated the instructions for each exercise. We recommend that this approach be used, as our users found the animated movements more effective, than static images and text, at conveying the correct range and pace of movement required.

CONCLUSION

This paper describes a pilot randomized controlled trial to explore the long-term use of tailored exergames, to encourage adherence to a falls rehabilitation programme in the home. In this study, exergames were found to encourage adherence to the rehabilitation programme, compared to an instructional booklet. This was attributed to increased levels of engagement provided by the exergames, as well as technologies that were regarded as highly usable and acceptable. We did not find differences in changes in balance between groups. However, it was evident, from our findings, that the exergames have the potential to improve mobility by promoting effective quality of movement necessary for therapy. Furthermore, by increasing confidence, through the communication of progress, and reducing fear, exergames can potentially reduce the risk of falling in older adults.

This study describes the first known attempt to investigate the long-term use of computer-based exergames, designed in close collaboration with older users, for their rehabilitation in the home. This work demonstrates the potential of computer-based exergames in a currently unexplored area of HCI. Due to the limitations of this work, our results should be taken as suggestive rather than conclusive. However, the findings reported on in this paper can inform the design of a larger home study to further explore the potential of computer-based exergames for falls rehabilitation in the home.

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